Why study an exotic animal?
Or what can we learn from barn owls about neuroscience?

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Which model system?

Animals that lend themselves to combined behavioral and neurophysiological work.

Specialist or Generalist?
Sound localization

Sensory maps plasticity and development

Multisensory integration

Selective attention

Spatial representation in the hippocampus
Barn owls as model system for sound localization

- Facial ruff serves as a sound amplifier
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- Asymmetric ears allow for an increased spatial resolution in the vertical plane
Barn owls as model system for sound localization

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- Asymmetric ears allow for an increased spatial resolution in the vertical plane
- Comb-like structures at the leading edge of the wing reduce noise during flight
Barn owls as model system for sound localization

Facial ruff serves as a sound amplifier

Asymmetric ears allow for an increased spatial resolution in the vertical plane

Comb-like structures at the leading edge of the wing reduce noise during flight

Brain structures involved in the analysis of sound are enlarged
Performing a psychoacoustic experiment with an owl
Sound-localization with free-field stimuli

\[\beta \text{ turning angle [deg]} \]

\[\alpha \text{ stimulus angle [deg]} \]

NLS

RLS

\[\beta \]

\[\alpha \]
• The auditory localization cues:

• ITD - horizontal

  location producing
  ITD = 0 µsec

  location producing
  ITD = 100 µsec

ILD - vertical
Precision of sound localization in barn owls may be as good as 3 deg which corresponds to 6-10 µs.
These signals are the “language” of neural processing.
Durations of events

• Typical duration of action potential: 1 ms
• Typical duration of post-synaptic potentials: 5-10 ms
• Precision of sound localization by interaural time difference: 6-10 μs

What has to be explained is

Factor of 500-1000
The principle of phase locking as a means to conserve time

Sinusoidal signal

Presumed resulting postsynaptic potential

Registered signal in computer

Note that in this example the response always occurs at a phase of 180 degrees.
Phase locking can be measured by plotting spike arrival times with respect to the period of the stimulus tone.

Precision of phase locking is 35 μs at 5 kHz (Köppl (1997)).
Jefferess model (1948)

Coincident detector neurons
Jefferess model (1948)
Does the brain computes ITDs as Jefferess suggested?

Nucleus Laminaris / Medial Superior Olive - sites of binaural convergence
Anatomical evidence for Jeffress model
ITD curves in Inferior colliculus
SOUND LOCALIZATION

Forebrain
- Sensory/Association Areas
  - Ovoidalis (MGN)
  - Rotundus (Pulvinar)

Thalamus
- Inferior Colliculus central n.
- Inferior Colliculus external n.
  - VLVp (LSO/DNLL)
  - LAM (MSO)
  - left cochlear n.
  - right cochlear n.

Midbrain
- Optic Tectum (SC)
  - Brainstem Tegmentum
    - Motor Nuclei for gaze control

GAZE CONTROL

Brainstem

LAM (MSO)
ITD (µs) vs. Response

ILD (dB) vs. Head Image
Visual and auditory maps in the OT
Computational map

Transducing sound to action-potentials

Computing auditory localization cues

Integrating cues from specific locations

Associating with external space

Sound

Frequency

Intensity

Time

Side of ear

Frequency

Binaural localization cues

Space tuned
Computational maps
The matching problem

location producing
ITD = 0 μsec

location producing
ITD = 100 μsec
Computational maps
The matching problem

location producing
ITD = 0 μsec

location producing
ITD = 100 μsec
Immediate Effect of Prisms

Effect of prism experience on auditory tuning

Normal

Immediate effect of prisms

After 8 weeks of prism experience
Quantification of learning

1. Behavioral test

2. Physiological test
Decline in learning with age

Increased capacity for learning in adults that have had appropriate experience as juveniles

Effects of juvenile experience on adult learning

Incremental learning
Incremental learning

Rich and lively experiences increase learning capacity in adults

Bergan et al., Journal of Neuroscience (2005)
Summary

- Decline in learning with age
- Increased capacity for learning in adults that have had appropriate experience as juveniles
- Incremental training improves learning
- Rich and lively experiences increase learning capacity in adults
Where is the site of plasticity?

Forebrain
- Sensory/Association Areas
- Archistriatum (FEF)

Thalamus
- Ovoidalis (MGN)
- Rotundus (Pulvinar)

Midbrain
- Inferior Colliculus central n.
- Inferior Colliculus external n.
- Optic Tectum (SC)
- VLVp (LSO/DNLL)
- LAM (MSO)

Motor Nuclei for gaze control
- Brainstem Tegmentum

left cochlear n.
right cochlear n.
Horizontal section through the tectal lobe

Visual input from Retina and Forebrain

- ICC
- ICX
- OT

Visual input angles:
- 0°
- 20°
- 40°
Site of plasticity in the ICX

Debello et al., J. Neurosci. 2001
After prism learning

Visual input from Retina and Forebrain
The instructive signal

- Operates in the ICX
- Visually based
Where is the instructive signal coming from?
BDA injection site in ICX

250 µm
Topography of the OT-ICX projection
Restricted lesion of the optic tectum
How can a visually based instructive signal act in an auditory structure?
Horizontal section through the tectal lobe

Visual input from Retina and Forebrain

ICC

OT

ICX

r

m

l

c

20°

40°

20°

0°

0°
Light responses in the ICX
Properties of visual responses in ICX

- Arrive from the OT

- Display spatially restricted visual receptive fields

- Form a map of space

- Align with auditory spatial representation
Bimodal Stimulus

light
right ear
left ear
Visual and auditory interactions in the ICX

![Graph showing ITD vs. Post stimulus time]
Average

![Graph showing ITD (μs) vs. Post stimulus time (ms) and AV-A (spikes)]
Bimodal stimulus

Normal

Visual input

ICC
ICX
OT
Bimodal stimulus

Normal

With prisms

Visual input

ICC
ICX
OT

ICC
ICX
OT
Bimodal stimulus

Normal

With prisms

Visual input

ICC

ICX

OT

ICC

ICX

OT
Summary

• An inhibitory gate controls the flow of visual information into the auditory system

• The visual signals are appropriate to serve as the instructive signal for auditory plasticity
Final Summary

• Studies in barn owls provided important insights on sound localization.

• Auditory map plasticity in barn owls is the first solved vertebrate example of experience-dependent plasticity.
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